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* AGARD (Advisory Group for Aerospace Research and Development) was a scientific panel that advised the NATO (North Atlantic Treaty Organization) on "problems, prospects, and possibilities in the nuclear propulsion field".
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In its preface to the book NUCLEAR THERMAL AND ELECTRIC PROPULSION Fundamentals, Systems, and Applications AGARD First and Second Lecture Series in cooperation with the Université Libre de Bruxelles 12-21 November 1962 28 September-2 October 1964 by R.A. Willaume (AGARD Director Plans and Programmes), A. Jaumotte (Faculté des Sciences Appliquées, Université Libre de Bruxelles), R.W. Bussard (Space Technology Laboratories, Course Director). Published by Gordon and Breach Science Publishers, 1967, it made this tribute to Theodore von Karman:

"Through the vision and foresight of the late Dr. Theodore von Karman, founder and General Chairman of the Advisory Group for Aerospace Research and Development of the NATO nations, a lecture series was planned and held in November, 1962. . . This first lecture course was concerned principally with the exposition of the fundamentals of nuclear thermal and electric propulsion (italics mine) and was held in order to acquaint a high level technical group from the NATO nations with the basics of a relatively new field which promised much for the future of aerospace propulsion systems. . . The enthusiastic reception with which the material was met by the European technical community involved, prompted both Dr. von Karman and R. Willaume to initiate plans for a second lecture series aimed at exploring more specific features of each class of nuclear propulsion systems. . . ."

The table of contents contain the following subjects:

Fundamentals of Nuclear Propulsion
Isotope/Thermal Thrusters and Applications
Fast and Moderate Reactors and Applications of Low-Power
Nuclear Rockets
Nuclear Rockets Based on Graphite Reactors
Technology: Applications and Development Status
Operational Considerations, Radiation Hazards and Safety
Nuclear Space Power Systems: Reactors, Conversion Equipment
and Power Systems Technology
Advanced Technology for Large Space Power Systems
Electric Propulsion: Systems, Flight Mechanics, Power Sources,
and Mission Applications

In order to summarize the material covered at the 1962 and 1964 lectures,

~~the development of nuclear reactors and electric drive systems~~

It must be remembered that it was von Karman who pushed the Air Force to utilize nuclear energy as a power source for high speed aircraft and rockets in the mid-forties. Also, he advanced the knowledge gained from the practical applications of flying-wing designs that were more than 50 years ahead of its time. Also another point of note. It was President John F. Kennedy that as well advocated space exploration as no American president did. Again, it was von Karman and German scientists that designed and created the NASA Gemini and Apollo programs that allowed human beings to go to the moon and return.

FUNDAMENTALS OF NUCLEAR PROPULSION--R.W. Bussard, TRW Space Technology Laboratories, Inc., Redondo Beach, California.

OUTLINE

- I. PERFORMANCE ANALYSIS
 - A. External Ballistics
 - B. Internal Dynamics
- II. REACTOR NEUTRONICS
 - A. Basic Principles of Fission Reactors
 - B. Criticality and Time-Dependence

I kept secret details
see no reason to keep this file
classified. I will have good deletion
check with A.P. work I do not
see any problems with dissemination
R. Bussard

- III. RADIATION LEAKAGE AND SHIELDING
Downgraded at 12 year intervals--Not Automatically Declassified
A. Radiation Sources and Performance
B. Heat Exchanger and Nozzle Performance
C. Attenuation Mechanics and Shield Design
Unsanctioned disclosure subject to administrative and criminal sanctions
IV. HEAT TRANSFER AND FLUIDS
Section 144b, Atomic Energy Act, 1954.
A. Heat Transfer Mechanisms
B. Heat Exchanger and Nozzle Performance
V. MATERIALS REQUIREMENTS AND PROPERTIES
A. Propellants and Their Performance
B. Fuel Element Materials
C. Moderators and Reflectors
VI. REACTOR DESIGN AND ENGINE CYCLE CONSIDERATION
A. Reactor Design Principles
B. Engine Cycles and Selection

FILE

2

PERFORMANCE ANALYSIS-

A. EXTERNAL BALLISTICS

1. "the basic equations of motion. . . derived from Hamilton's principle of least action" "

"Euler-Lagrange equations for the motion of a conservative dynamical system"

". . . include the non-conservative accelerating force F from rocket motor."
TOP SECRET 7
2. "In considering the transfer of a rocket vehicle from one planet to another it is not sufficient to consider only the free Newtonian orbits between planetary radii. . . . We must also account for the gravitational fields of the launching and target planets. . . . For high acceleration vehicles the velocity increment requirements at each end of the journey can be taken as the root-sum-square values. Then the total one-way mission velocity requirement will be the linear sum of the two subtotals needed at each end point. . . . For a round-trip mission this must be doubled."
3. "Other losses of interest are those due to atmospheric drag, to atmospheric effects (nozzle back pressure, etc.) and to propellant consumption for turbine drive use."
4. "The types of propulsion systems proposed for low-acceleration vehicles are often such that the exhaust speed may be varied as desired over a wide range. This is particularly true of nuclear/electric ion plasma propulsion systems."

B. INTERNAL DYNAMICS

1. "The rationale of system analysis is to provide guide lines for design of the vehicle and/or engine. This can be done only if ways are found to connect internal engine parameters with external performance parameters of the vehicle. In rocket flight this can be done because the size or mass of most of the internal components is set by either the power or energy cost of the vehicle flight, and these in turn determine the external behavior. . . . These are the tank and structure, propellant, dead load, nuclear rocket motor, and turbo pump plant. . . . Tank and structure mass is related to propellant mass and density. . . . Turbo pump mass is related to discharge pressure and volumetric flow rate by where the second equality is derived by use of the rocket thrust equation. Nuclear rocket motor mass is roughly linearly proportional to power output."
2. "Ground launching. . . poses more difficult reactor design and development problems than does launching from free-fall. . . . Another feature of interest in use of heat exchanger nuclear rocket motor propulsion systems arises from the interrelation of reactor specific mass and propellant specific impulse. . . it is clear that a connection does exist if increased gas temperature is to be gained by varying choice of fuel element materials, since materials which offer highest melting point may be denser than those for lower temperature use."

A. GENERAL DISCUSSION

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Minimum performance and safety requirements. Establish design criteria for the thruster, the isotope capsule and the fuel form within that capsule. For instance, to be useful, isotope thrusters must operate at high temperatures.

In recent years the program conducted by the AEC's Division of Isotopes Development has made great strides toward development of stable, refractory fuel forms capable at the required temperatures. This section discusses isotope heat-source technology which encompasses both isotope technology and capsule technology.

B. ISOTOPE TECHNOLOGY

I. Introduction

Radioisotopes, when they decay, emit thermal energy in a completely predictable fashion and at a rate governed by their half-lives. They, therefore, represent a compact, reliable source of heat which will continue to function independently of the surrounding environment. Radioisotopes are obtained either as by-products of fission reactor operation or are formed by neutron bombardment of target material in a reactor.

Alpha particles, because of their large mass and high positive electrical charge, have an extremely small range in solid material (measured in microns). For this reason almost 100% of their energy is converted into heat within the fuel capsules. Similarly, beta particles are completely stopped by $\frac{1}{4}$ in. of aluminum so that their kinetic energy is almost entirely converted into heat within the fuel capsules*.

One disadvantage associated with alpha emitters is the helium buildup within the containment vessel. Upon emission from the nucleus of the isotope, alpha particles, which are helium nuclei, combine with free electrons and form helium atoms. . . It is not yet known whether the helium gas formed escapes by diffusion or is absorbed interstitially, or merely remains as free gas and increases the pressure within the fuel capsule. . . No definite conclusion has yet been reached. Pending better resolution of this question all current designs are based on the assumption that the helium appears as a pressure-producing perfect gas within the capsule.

2. Selection Criteria

. . . for potential high-temperature heat source application indicates the following possibilities: Sr-90, Pm-147, Pu-238, Po-210, Cm-244, Ru-106, Ce-144, and Cs-137.

The choice of an isotope for a given space application depends on the following factors:

- (1) Temperature capability of available fuel forms must satisfy mission requirements.
- (2) Half-life must be adequate for mission requirements.
- (3) Power density must be sufficient to prevent excessive weight penalties.
- (4) Isotope must have a potential availability which is compatible with mission requirements.
- (5) Isotope projected costs must be reasonable.
- (6) Radiation levels must be compatible with mission limitations.

* The beta particles are decelerated by interaction with electronic fields surrounding the nuclei of the material through which they are passing. As a result of this interaction some of the energy of the decelerated beta particle is emitted in the form of electromagnetic radiation known as bremsstrahlung.

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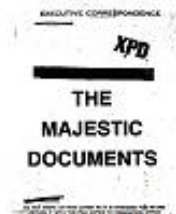
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